

Cryogenic Behavior of the High Temperature Crystal Oscillator PX-570

Richard Patterson, NASA Glenn Research Center

Ahmad Hammoud, ASRC Aerospace, Inc. / NASA GRC

Steven Scherer, INSPIRE Summer Intern, NASA GRC

Background

Microprocessors, data-acquisition systems, and electronic controllers usually require timing signals for proper and accurate operation. These signals are, in most cases, provided by circuits that utilize crystal oscillators due to availability, cost, ease of operation, and accuracy. Stability of these oscillators, i.e. crystal characteristics, is usually governed, amongst other things, by the ambient temperature. Operation of these devices under extreme temperatures requires, therefore, the implementation of some temperature-compensation mechanism either through the manufacturing process of the oscillator part or in the design of the circuit to maintain stability as well as accuracy. NASA future missions into deep space and planetary exploration necessitate operation of electronic instruments and systems in environments where extreme temperatures along with wide-range thermal swings are countered. Most of the commercial devices are very limited in terms of their specified operational temperature while very few custom-made and military-grade parts have the ability to operate in a slightly wider range of temperature. Thus, it becomes mandatory to design and develop circuits that are capable of operation efficiently and reliably under the space harsh conditions. This report presents the results obtained on the evaluation of a new (COTS) commercial-off-the-shelf crystal oscillator under extreme temperatures.

Test Procedure

The device selected for evaluation comprised of a 10 MHz, PX-570-series crystal oscillator. This type of device was recently introduced by Vectron International and is designed as high temperature oscillator [1]. These parts are fabricated using proprietary manufacturing processes designed specifically for high temperature and harsh environment applications [1]. The oscillators have a wide continuous operating temperature range; making them ideal for use in military and aerospace industry, industrial process control, geophysical fields, avionics, and engine control. They exhibit low jitter and phase noise, consume little power, and are suited for high shock and vibration applications. The unique package design of these crystal oscillators offers a small ceramic package footprint, as well as providing both through-hole mounting and surface mount options. Table I shows some of the manufacturer's specifications for this device [1].

Table I. Manufacturer's specifications of PX-570 crystal oscillator [1].

| Parameter | |
|--|-----------------------|
| | |
| Operating voltage (V) | 3.3 |
| Frequency (MHz) | 10 |
| Input current (mA) | 5 |
| Operating temperature (°C) | 0 to +230 |
| Duty cycle (%) | 40 to 60 |
| Frequency tolerance (ppm) | ± 300 |
| Output rise/fall time (ns) | 1 to 3 |
| RoHS Compliant, ceramic leaded package | 6-pin 8.0 mm x 8.5 mm |
| Part # | PX-5701-EA3 YXXX-10M |
| Lot number | 256280-1122 |

Operation stability of this crystal oscillator was investigated under exposure to extreme temperatures. Performance characterization was obtained in terms of the oscillator's output frequency, duty cycle, rise and fall times, and supply current at specific test temperatures. Re-start capability at extreme temperatures, i.e. power switched on while the device was soaking at extreme (hot or cold) temperature, was also examined. The effects of thermal cycling under a wide temperature range on the operation of the crystal oscillator were also investigated. The oscillator was subjected to a total of 12 cycles in the temperature range of -125 °C to +230 °C at a temperature rate of 10 °C/minute and a soak time of 20 minutes at the temperature extremes. Figure 1 shows the test circuit board populated with the PXO-570 oscillator along with a couple of filter capacitors.

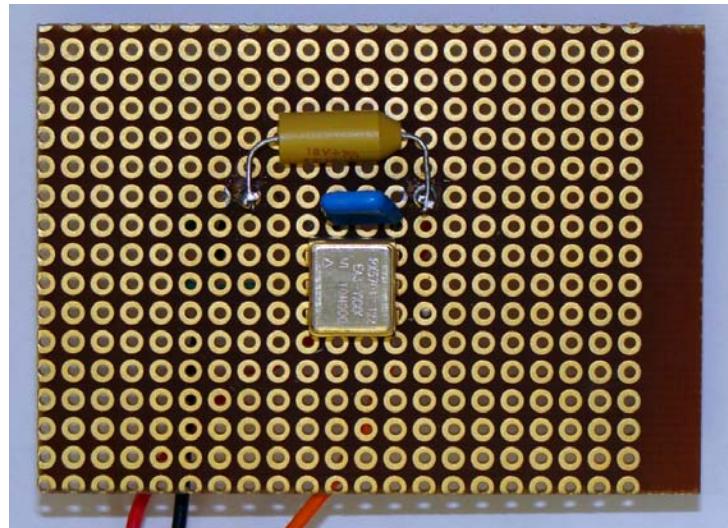


Figure 1. Oscillator chip and capacitors mounted on circuit board.

Test Results

Temperature Effects

The output frequency of the PX-570 crystal oscillator as a function of temperature is shown in Figure 2. The oscillator operated successfully throughout the entire test temperature range of -125°C to $+230^{\circ}\text{C}$ with very slight variation in its output frequency, most notably at the extreme high temperatures. These variations, as depicted in Figure 2, are reflected by a gradual but slight increase in the output frequency of the oscillator as the applied test temperature was above $+180^{\circ}\text{C}$. At the highest test temperature of $+230^{\circ}\text{C}$, for example, the oscillator's frequency attained a value of 10.0052 MHz as compared to the room temperature magnitude of 9.9993 MHz. This increase in frequency amounted to 0.06%. In the cryogenic region, while the oscillator functioned extremely well with excellent stability in its output frequency with temperature down to -125°C , it exhibited intermittent operation in the range of -125°C to -130°C , and it ceased to work as test temperature lowered below -130°C . It appeared that this inoperability of the crystal oscillator at the extreme cryogenic temperature was transitory in nature as the circuit completely recovered when the test temperature was increased above -130°C . It should be pointed out that the crystal oscillator was allowed to soak for at least half-hour at these decisive test temperatures in the environmental chamber prior to recording the data. Given the fact that this crystal oscillator is only rated for operation between 0°C and $+230^{\circ}\text{C}$, this preliminary evaluation of its performance suggests that this range could be extended at the low temperature end provided more comprehensive and long term testing are done to corroborate its usefulness also in cryogenic applications. A typical waveform of the frequency output at 22°C is shown in Figure 3.

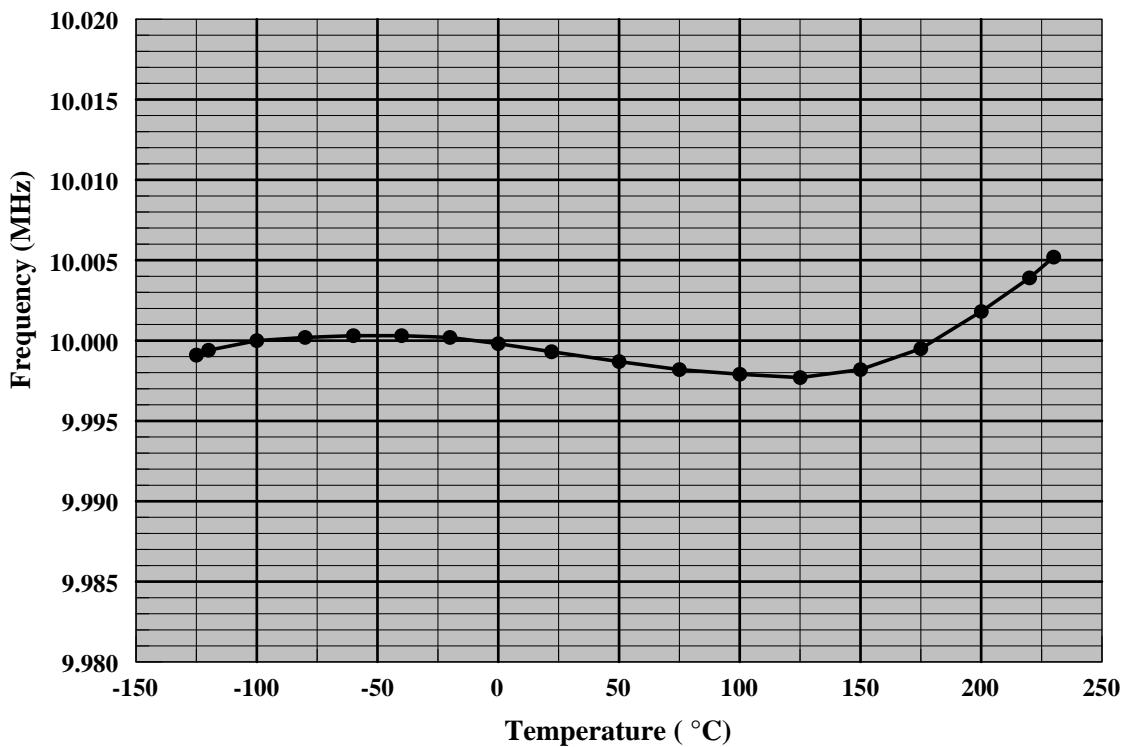


Figure 2. Variation in oscillator output frequency with temperature.

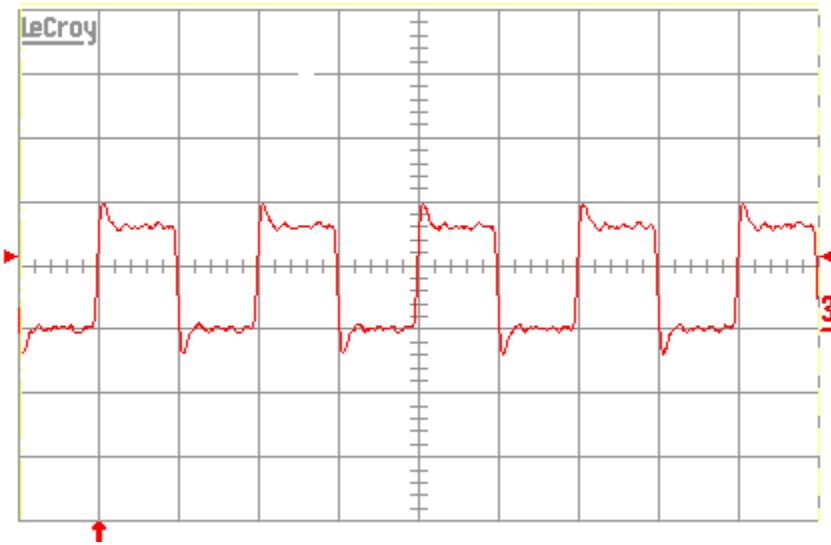


Figure 3. Output waveform of the PX-570 crystal oscillator at room temperature.
 (Scale: Horizontal 50 ns/div, Vertical 2 V/div)

Similar to the frequency, the duty cycle of the output signal did not display any significant change with temperature as it retained a value around 50% throughout the whole test temperature range between -125 °C and +230 °C, as depicted in Figure 4.

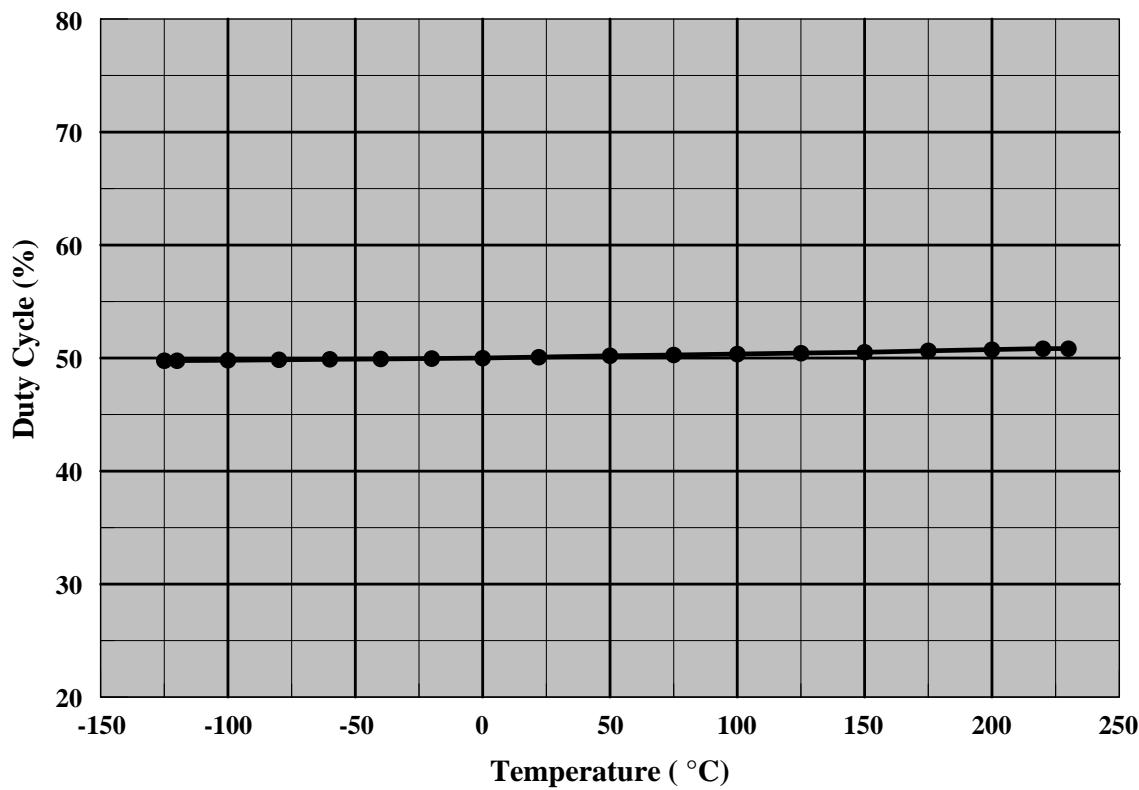


Figure 4. Duty cycle of oscillator output versus temperature.

The rise time as well as the fall time of the output signal displayed similar but weak dependence on temperature, as shown in Figure 5. Both of these characteristics were found to exhibit gradual but very small reduction in their values as temperature was decreased below room temperature; and the reverse was true when the circuit was exposed to high temperatures. The changes occurring at high temperature were slightly more profound, as displayed in Figure 5.

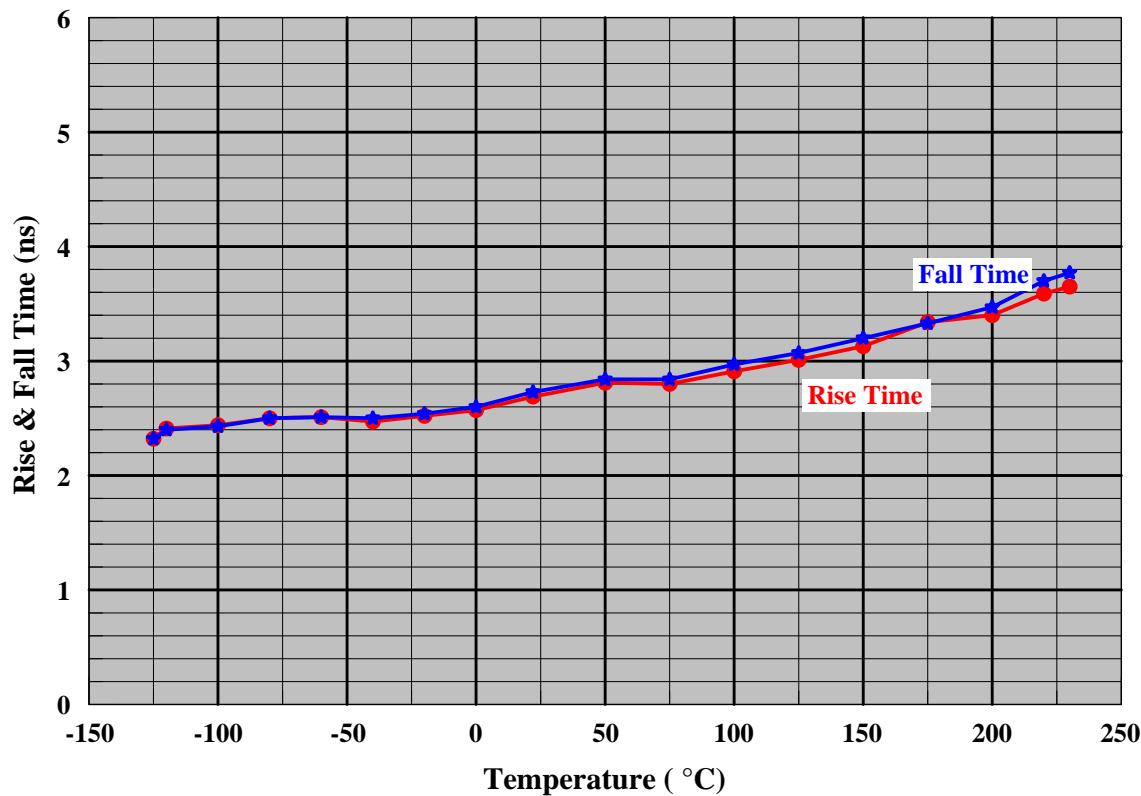


Figure 5. Rise and fall times of output signal versus temperature.

Negligible effect of test temperature on the supply current of the PX-570 crystal oscillator was observed as the value of the current hovered around 4 mA throughout the test temperature range between -125 °C and +230 °C, as shown in Figure 6.

Re-Start at Extreme Temperatures

Re-start capability of this PX-570 crystal oscillator was investigated at the extreme test temperatures of -125 °C and at +230 °C. The oscillator chip was allowed to soak at each of those two temperatures, with electrical power off for at least 20 minutes. Power was then applied to the circuit, and measurements of the oscillator's output waveform characteristics and frequency were recorded. The oscillator circuit successfully operated under cold start at -125 °C as well as at the hot temperature of +230 °C, and the data obtained was similar to those obtained earlier at these respective temperatures.

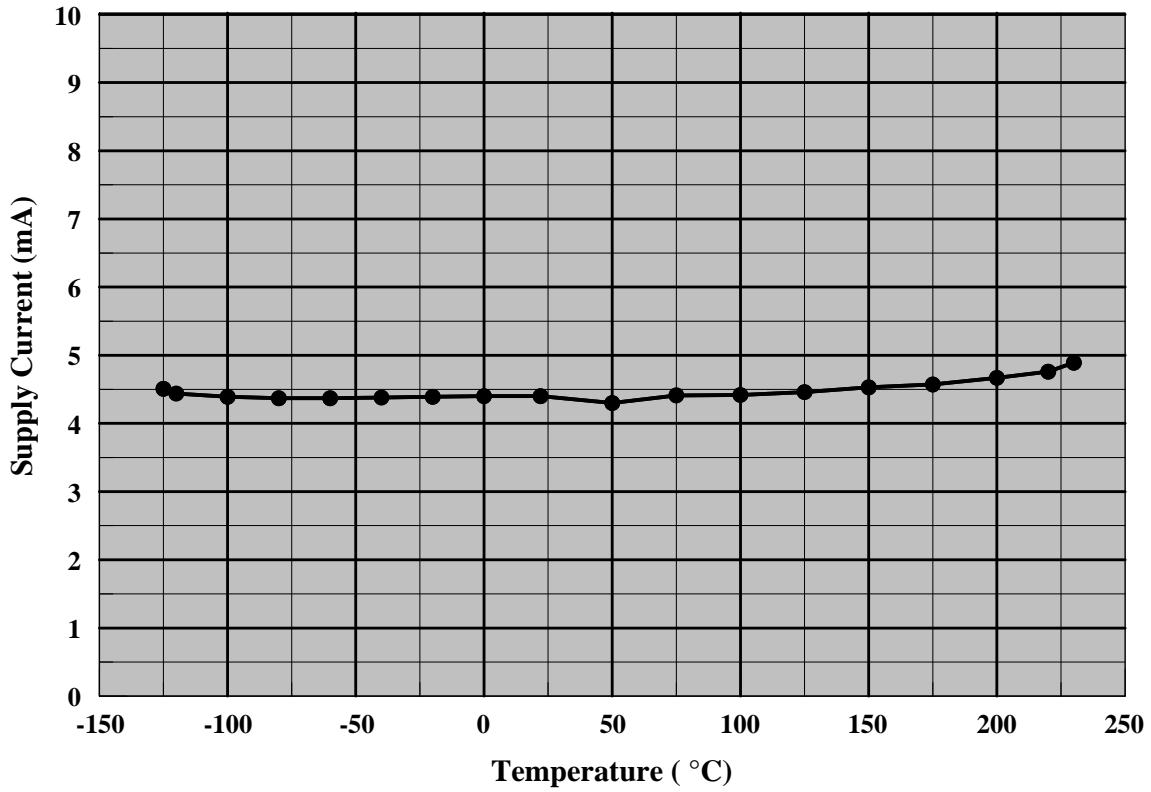


Figure 6. Supply current of oscillator as a function of temperature.

Effects of Thermal Cycling

The effects of thermal cycling were investigated by subjecting the crystal oscillator chip to a total of 12 cycles between -125 °C and +230 °C at a temperature rate of 10 °C/minute. Although this short-term activity does not replace highly accelerated or life testing for reliability determination, it provides, nonetheless, some preliminary insight on the effect of thermal cycling on the device's behavior. During cycling, a dwell time of 20 minutes was applied at the extreme temperatures. Post-cycling measurements on the characteristics of the oscillator circuit were then performed at selected test temperatures. Table II lists post-cycling data along with the data obtained prior to cycling. A comparison between pre- and post-cycling data reveals that this oscillator did not undergo any significant changes in its operational characteristics due to this limited cycling; as also evidenced by the consistency in the output waveforms shown in Figure 7 that were recorded at selected temperatures before and after the cycling. The thermal cycling also appeared to have no effect on the structural integrity of the device as no packaging damage was noted upon inspection.

Table II. Pre- and post-cycling characteristics of the PX-570 crystal oscillator.

| T(°C) | Cycling | f (MHz) | Duty cycle (%) | T_{rise} (ns) | T_{fall} (ns) | I_S (mA) |
|--------------|----------------|----------------|-----------------------|------------------------------|------------------------------|---------------------------|
| -125 | pre | 9.9993 | 50.08 | 2.69 | 2.73 | 4.4 |
| | post | 9.9994 | 50.1 | 2.8 | 2.78 | 4.45 |
| 22 | pre | 9.9991 | 49.77 | 2.32 | 2.32 | 4.51 |
| | post | 9.9994 | 49.78 | 2.49 | 2.49 | 4.47 |
| +230 | pre | 10.0052 | 50.84 | 3.65 | 3.77 | 4.89 |
| | post | 10.0048 | 50.83 | 3.65 | 3.72 | 5.02 |

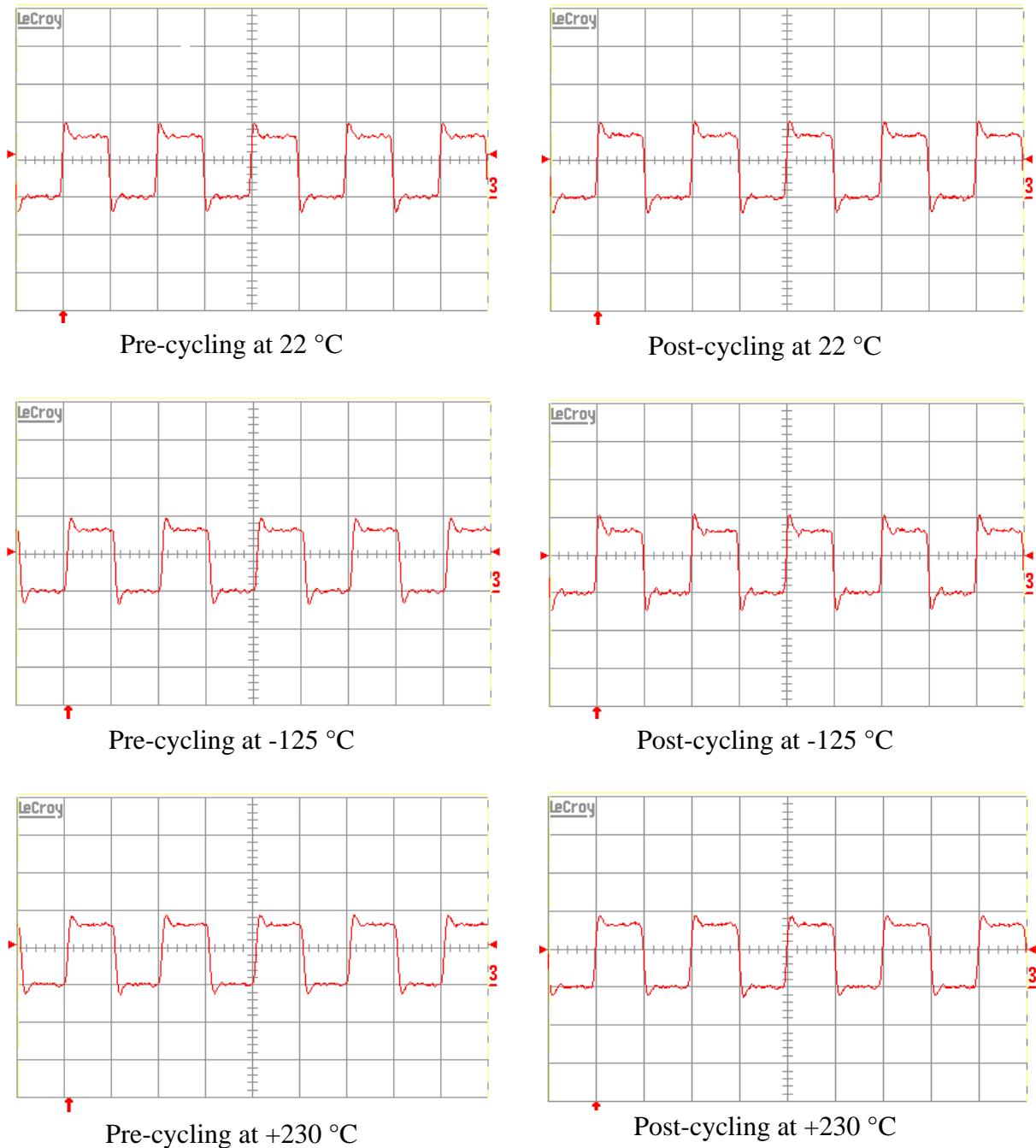


Figure 7. Pre- and post-cycling oscillator output waveforms at 22, -125, and +230 °C.

Conclusions

A recently-developed commercial-off-the-shelf crystal oscillator was characterized under exposure to extreme temperatures and wide-range thermal cycling. The Performance of the Vectron PX-570 oscillator was evaluated in terms of its frequency stability, output signal rise and fall times, duty cycle, and supply current at specific test temperatures. The effects of thermal cycling and re-start capability at extreme hot and cold temperatures were also investigated. The crystal oscillator operated quite well with very good frequency stability over the temperature range of -125 °C to +230 °C. This temperature operating range exceeded its recommended specified limits between 0 °C and +230°C. Similarly, the oscillator circuit experienced no change in its behavior after undergoing limited thermal cycling between -125 °C and +230 °C, and was able to re-start at the extreme temperatures. In addition, no damage was observed in the packaging material due to the extreme temperature exposure or thermal cycling. These preliminary results indicate that the device has the potential for operating also in cryogenic environments and in applications where wide-range thermal swings are present. Additional long-term testing is, however, required to fully establish the reliability of these devices and to determine their suitability for use in space exploration missions under extreme temperature conditions.

References

- [1]. Vectron International, “PX-570 High Temperature Crystal Oscillator” Data Sheet, Rev: 11/2008. <http://www.vectron.com>

Acknowledgments

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